N71-16576

NASA TECHNICAL MEMORANDUM

NASA TM X-52953

NASA TM X-52953

PUMPING CHARACTERISTICS OF A ROTATING TRUNCATED CONE

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Cleveland, Ohio
January, 1971

This information is being published in prelimi-
nary form in order to expedite its early release.

ABSTRACT

Pumping characteristics of a rotating truncated cone having a major diameter of 20.3 cm and a minor diameter of 12.7 cm were determined at speeds up to 30,000 rpm. The surface of the cone had a semi-apex angle of 45 degrees and a constant radial gap of .406 cm. Operating characteristics could be approximated using equations for enclosed rotating disks.

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SUMMARY

A smooth-surface Lundell-type of alternator rotor having conical sections with a major diameter of 20.3 cm and a minor diameter of 12.7 cm was operated as a pump at speeds from 0 to 30,000 rpm. The conical surface had a semi-apex angle of 45 degrees and a gap width of .406 cm. Head-flow characteristics were determined at three operating speeds; 18,000, 24,000, and 30,000 rpm. It was found that the operating characteristics could be approximated by equations for enclosed rotating disks.

INTRODUCTION

A Lundell generator is being investigated for use in Brayton cycle space power systems (ref. 1). At the speeds involved (24,000 rpm and 36,000 rpm), a significant amount of heat is generated by windage losses. One method under consideration to remove this heat is to circulate the alternator cavity gas through a heat exchanger by means of the pumping characteristics of the conical sections. The gas flow in the rotor-stator gap is turbulent. Taylor, Wendt, and Pai (refs. 2, 3, and 4, respectively) have studied turbulent flow for concentric cylinders. However, these studies were made using large gaps, viz., gap-to-radius ratios of 0.1 to 0.23. Reference 5 presents a preliminary study of windage losses for concentric rotating cylinders using gap-to-radius ratios of 0.01 to 0.04, the range considered for space power alternators. Studies of enclosed rotating disks producing turbulent flow can be found in references 6 and 7; the gap-to-radius ratios for these investigations ranged from 0.01 to 0.22. No information is available on the pumping characteristics of enclosed rotating conical sections.

A Lundell type of rotor having conical sections with a major diameter of 20.3 cm and a minor diameter of 12.7 cm was tested at speeds from 0 to 30,000 rpm. The conical surface had a semi-apex angle of 45 degrees and a constant gap width of 0.406 cm. The head-flow characteristics of the conical sections were determined at the three rotational speeds of 18,000, 24,000, and 30,000 rpm. For the tests the rotor was surrounded by ambient air.

SYMBOLS

D	characteristic dimension
g	acceleration of gravity
H	pressure head
N	speed
Q	volumetric flow rate
Q_1	inlet volumetric flow rate
r_i	minor cone radius
r_o	major cone radius
T_o	standard temperature, 288.15^o K
T_1	inlet temperature
ΔP	pressure rise
ρ	density
ω	angular velocity

APPARATUS

The pump test apparatus consisted of a stator housing and a smooth rotor supported at each end on ball bearings. The stator was fixed to the test bed. A variable-speed dynamometer was used to drive the rotor. Figure 1 is a photograph of the pump with the upper half of the stator removed, the rotor and stator each having two conical sections operating as pumps in parallel.

A cutaway view of the pump in figure 2 shows pertinent dimensions and the location of the pressure and temperature instrumentation. The gas flow enters the rotor-stator clearance passage at each end of the rotor, then passes through each conical pumping section, and exits through five radial outlets spaced circumferentially about the stator; only one of these radial outlets is shown in figure 2. The flows from the five radial outlets are manifolded together and piped through both a flowmeter and a flow-control valve before being discharged back to the atmosphere.

Procedure

Each test run was started at zero speed with the flow-control valve in the closed position. As speed was increased in steps, speed, temperature and pressure data were taken for the "no-flow" condition. At 18,000, 24,000, and 30,000 rpm, flow was varied by using the control valve. After head-flow data were taken at 30,000 rpm, data for the "full-flow" condition were taken as speed was reduced in steps to zero. Speed, pressure, and flow were allowed to come to steady-state conditions at each point before the data were recorded.

INSTRUMENTATION

Rotational speed, flow, temperatures, and differential pressures were measured. Speed was measured by means of a magnetic pickup and a 60-tooth gear on the shaft of the dynamometer. The signal generated was sent to a counter and recorded. Rotational speed could be controlled within 5 rpm. Flow measurements were made using a turbine flowmeter. The output of the flowmeter was sent to a digital counter and recorded. Actual flow was then computed from a flowmeter calibration curve. Accuracy of flow measurement is estimated to be 5 percent.

All temperatures were measured using iron-constantan type-J thermocouples. Three bare-spike thermocouples were mounted on the housing, each extending halfway into the gap at the axial locations shown in figure 2. A fourth bare-spike thermocouple measured gas temperature at the inlet to the flowmeter.

The pumping head-rise in the conical sections was measured by means of a differential-pressure transducer having a full-scale range of 1.72 newtons per square centimeter. An integrating digital voltmeter measured the transducer output, and the transducer was calibrated using a precision Bourdon-tube pressure gage. Readings on the transducer had an accuracy of .15 percent of full-scale.

DISCUSSION OF RESULTS

Head-flow performance of the conical sections of the Lundell-type rotor operating at 18,000, 24,000, and 30,000 rpm is shown by the nondimensional curves in figure 3. The pressure coefficient is the ratio of the measured pressure rise to the kinetic energy of the fluid.

$$\frac{\Delta P}{1/2 \rho \omega^2 (r_o^2 - r_i^2)}$$

ΔP = pressure rise

ρ = density

ω = angular speed of rotor

r_o = major cone radius

r_i = minor cone radius

Pressure coefficient is proportional to the similarity parameter $H/(ND)^2$ where

H = pressure head

N = speed

D = characteristic dimension

The flow coefficient is the ratio of the axial flow velocity to the rotor velocity, and is proportional to the similarity parameter Q/ND^3. The actual term used is $Q_1/\omega r_o^3$ where Q_1 = inlet volume flow rate. Flow was measured at the common outlet for the two conical sections. All flow rates were related back to the inlet conditions using the perfect gas law. It was assumed that the flows were identical for the two pumps in parallel.

Figure 3 shows approximately one and one-half percent difference between each speed at the low flow end and 10 percent difference at maximum flow. Inlet temperature could not be maintained constant during the test. The curve for 18,000 rpm was obtained at 30 degrees C $\pm$ 3.5 degrees C; at 24,000 rpm the temperature was 46 degrees C $\pm$ 8.5 degrees C; and at 30,000 rpm the temperature was 63 degrees C $\pm$ 11 degrees C.

The deadhead (no-flow) pressure rise for the rotating truncated cones can be predicted within 10 percent using equations given in reference 7 for enclosed rotating disks. The assumption must be made that the average core velocity is one-half the rotor speed. If either flow or pressure rise is given, the curves presented in reference 7 can be used to approximate the operating point. For design purposes, when a conical pump of this type is to be used in a system, the system operating point may be determined by superimposing a curve of system pressure drop vs flow on the pump characteristic curve in figure 3. The head rise will equal the system pressure drop. No surging (flow pulsation) was noted for the pump tested even with zero flow.

Figure 4 presents pump head rise $(\frac{\Delta P}{\rho g})$ vs corrected speed, $N\sqrt{\frac{T_o}{T_1}}$ where T_1 = inlet temperature, g = acceleration of gravity, and T_o = 288.15 degrees K. The two curves correspond to the deadhead and maximum flow cases. The deadhead pressure curve agrees with the curve presented in reference 8 for a similar rotating truncated cone with a gap of 0.203 cm (gap-to-radius ratio of 0.02). No effect of gap width was noted on the deadhead pressure. Head rise is seen to vary as the speed squared.

The curve in figure 5 shows the variation in inlet volume flow rate with corrected speed. The flow plotted corresponds to the maximum flow for the system tested. Flow is seen to vary directly with speed.

CONCLUSIONS

A smooth surface Lundell-type of alternator rotor having conical sections with a major diameter of 20.3 cm and a minor diameter of 12.7 cm was operated as a pump over a speed range from 0 to 30,000 rpm. The conical surface had a semi-apex angle of 45 degrees and a gap width of 0.406 cm. Head-flow characteristics were determined at 18,000, 24,000 and 30,000 rpm. Testing was conducted using ambient air. Results of the tests showed that:

1. For a given flow, the operating point of a conical pump can be approximated using equations for enclosed rotating disks.

2. The rotating truncated cones act as typical pumps with the head rise proportional to the speed squared and flow proportional to the speed.

3. The gap width has a negligible effect on the deadheaded pressure rise.

4. Acting as pumps, the conical sections were stable and did not surge at any flow, even zero.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, December 24, 1970.

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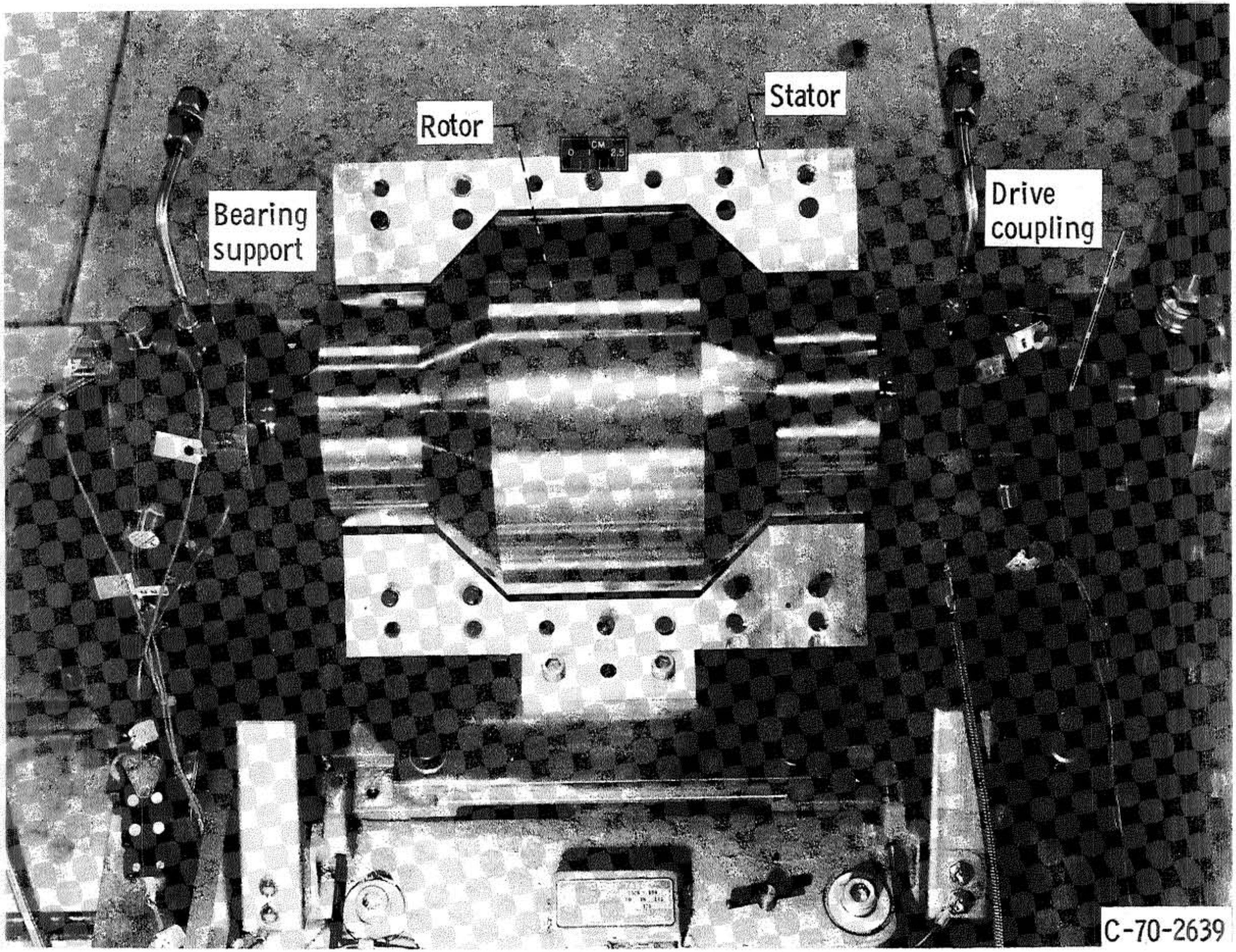

Figure 1. - Pump with upper half of stator removed.

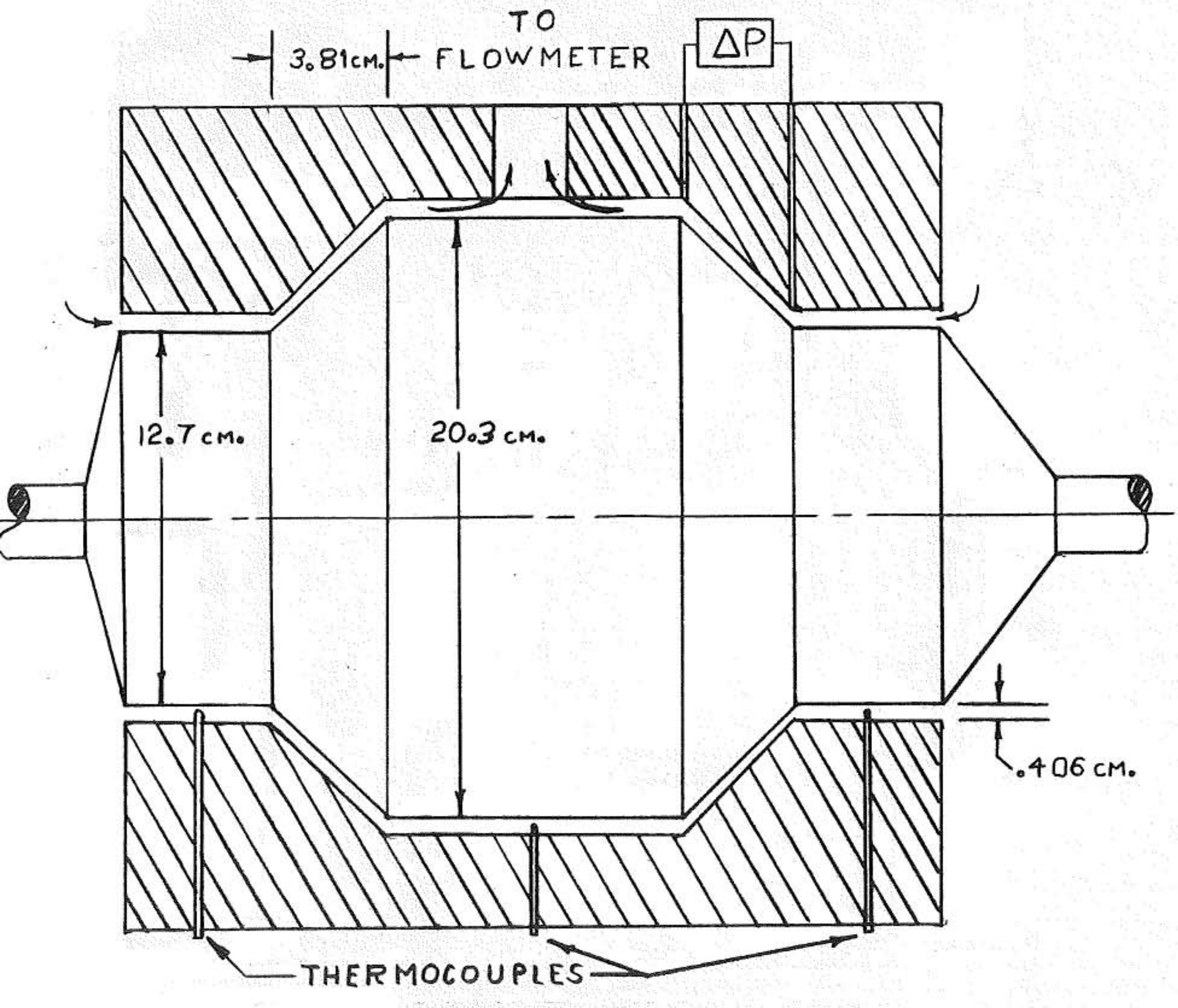

FIGURE 2. - CUTAWAY VIEW OF PUMP AND INSTRUMENTATION

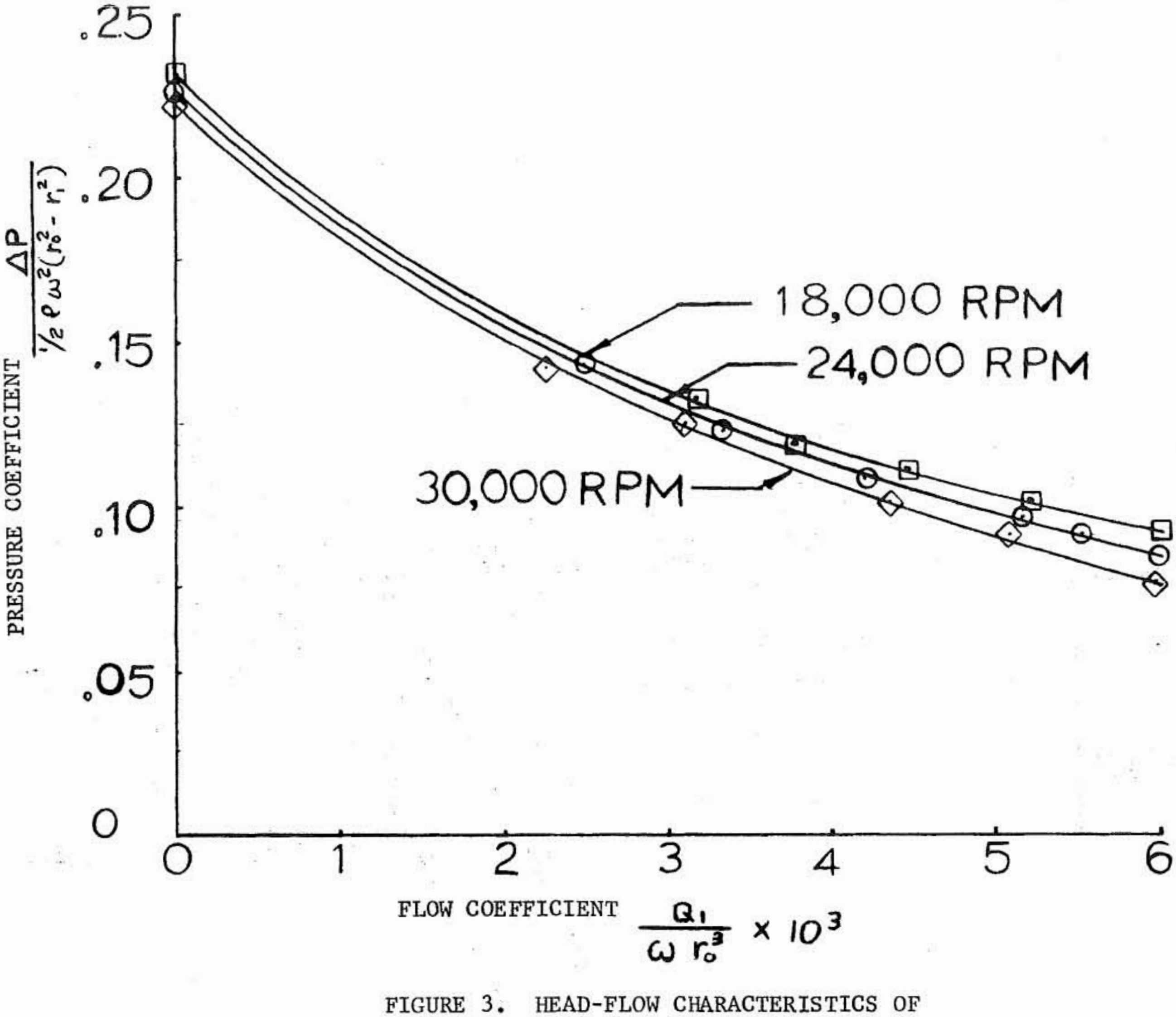

FIGURE 3. HEAD-FLOW CHARACTERISTICS OF THE PUMP AT THREE SPEEDS

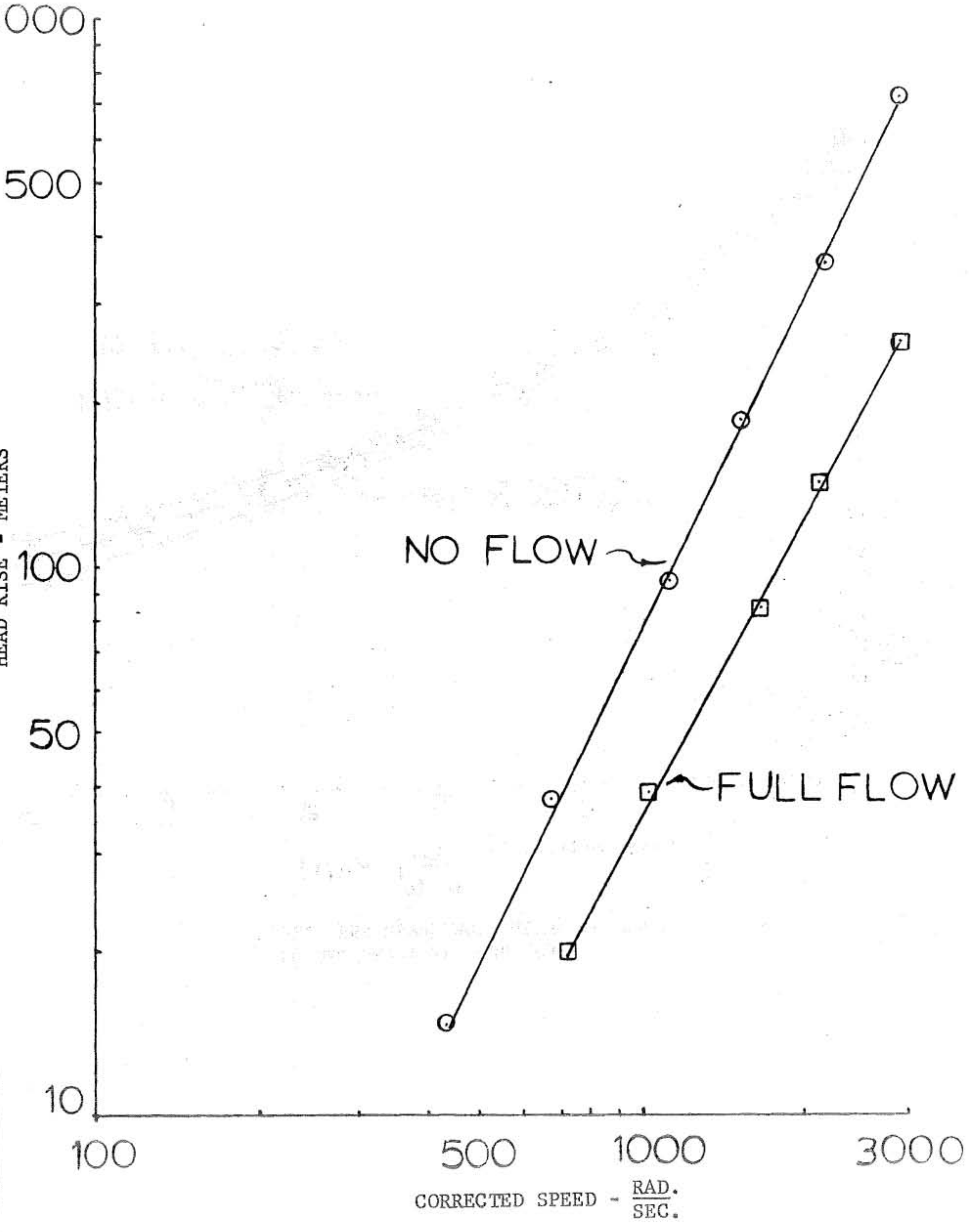

FIGURE 4. - HEAD RISE VERSUS CORRECTED SPEED FOR THE FULL FLOW AND NO FLOW CONDITIONS

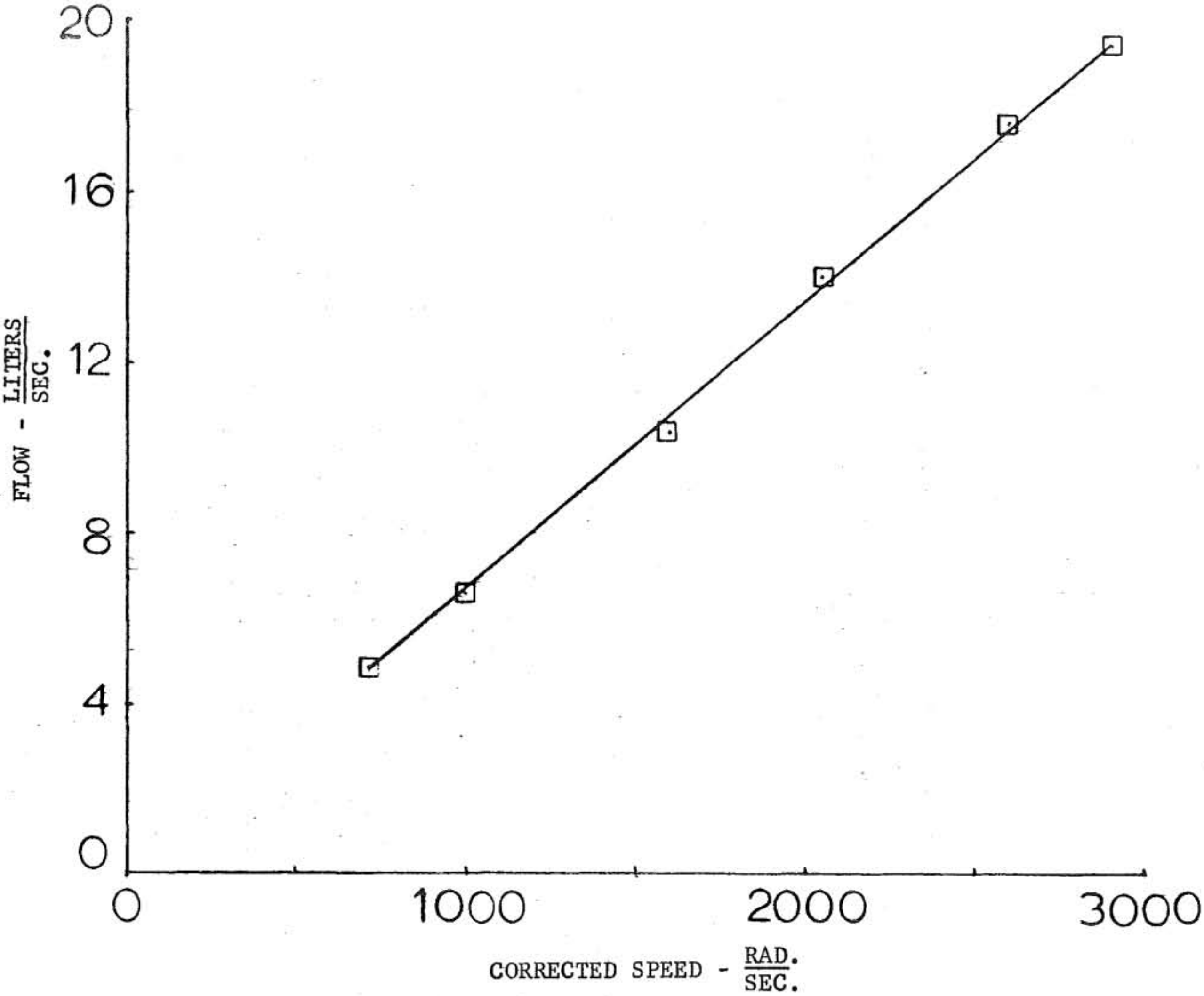

FIGURE 5. - VOLUME FLOW RATE VERSUS CORRECTED SPEED FOR MAXIMUM FLOW CONDITION